
LED balancing circuits

Introduction

Light Emitting Diodes (LEDs) are often used with an output voltage source from a power supply. The output voltage increases until the current through the LEDs reaches the value of the constant current source from the power supply. Maximum output voltage is limited by the power supply.

LEDs are used individually and when more light is required, LEDs are stacked in series with the same current passing through each one. The voltage across the string increases with each LED added. After a number of LEDs are added in series, the power supply may not be able to handle the higher output voltage required. Also, a change of output voltage could be a problem for the power supply if the range of LEDs required is high enough to increase the range of the output voltage and auxiliary circuits.

Various circuits can be used to balance the current in parallel strings of series loads where the individual loads vary in voltage, because LEDs have been shortened or opened. Without a circuit, the variation of the parallel loads could cause most, or all of the current to pass through the path of the load with the lowest voltage and a small amount of current through the path of the load with the highest voltage. The result would be a variation in light output and could cause LED failure from excessive current. The objective is to achieve the same current to pass through each parallel string of series loads even though the voltage across each load is not the same.

The following technical note is a description of three circuits which can be used to balance the current through two or more strings of LEDs. The power supply output voltage (LED circuit input voltage V_{in}) varies, up to a limit, while providing a constant current to the LED circuit. All of the circuits will balance the current in LED strings and protect for a shorted or open LED.

A power limit circuit is also described which limits the power of the LED balancing circuit when there is a large voltage variation for parallel strings of LEDs.

1 LED balancing circuits

1.1 LED balancing circuit 1 (see [Figure 1](#))

LED balancing circuit 1 (see [Figure 1](#)) contains two bipolar transistors and eight resistors. The current passing through each load (where a 'load' is one string of LEDs in series, for example, D1 and D2 or D3 and D4) is primarily the sum of the current through one resistor and one parallel transistor. When the load voltages are the same, an equal amount of current passes through the two transistors (Q1 and Q2) and an equal amount of current passes through the two resistors (R1 and R5).

When the load voltages are different, less current passes through the resistor with the lowest voltage (higher load voltage) and more current passes through the parallel transistor. For either case, the total current from both loads is constant (from the power supply) and the circuit will provide equal current through each load.

LED balancing circuit 1 uses LED loads D1 and D2, D3 and D4 and a power supply output voltage with a constant output current that provides the circuit input voltage (V_{IN}). The current through load D1 and D2 is the sum of the current through R1 and Q1. The current through the load D3 and D4 is the sum of the current through R5 and Q2. As each string contains the same number of LEDs, any number of LEDs can be used.

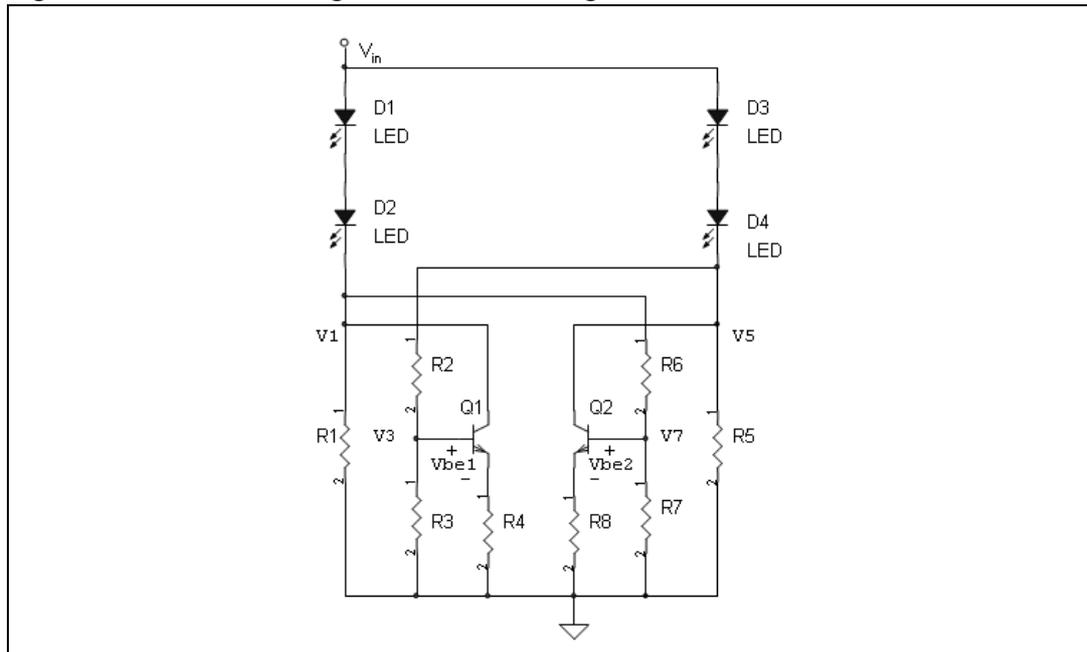
The voltage at V1 is the input voltage, minus the load voltage VD1 and VD2. The voltage at V5 is the input voltage, minus the load voltage VD3 and VD4. The current through R1 is the voltage V1 divided by the resistor R1, and the current through R5 is the voltage V5 divided by the resistor R5. The voltage at V3 is the voltage at V5 reduced by the divider resistors R2 and R3 ($V5 \times R3 / (R2 + R3)$) and the current through Q1 is V3 minus the base emitter voltage (V_{be_1}) divided by R4. The voltage at V7 is the voltage at V1 reduced by the divider resistors R6 and R7 ($V1 \times R7 / (R6 + R7)$) and the current through Q2 is V7 minus the base emitter voltage (V_{be_2}) divided by R8.

When the load voltages are equal, VD1 plus VD2 is equal to VD3 plus VD4, the voltage at V1 equals the voltage at V5, the current through R1 equals the current through R5, and the current through Q1 equals the current through Q2.

When the load voltages are not equal, VD1 plus VD2 is greater than VD3 plus VD4, V1 is lower, V5 is higher and the current through R1 is reduced. Since V5 is higher, the current through Q1 increases. The circuit values are selected so that the sum of the current through R1 and Q1 remains the same. Conversely, V5 is higher and the current through R5 is higher. Since V1 is lower, the current through Q2 decreases. The circuit values are selected so that the sum of the current through R5 and Q2 remains constant.

If one LED (D1) is open, there is no base current to Q2 through R6 and Q2 will turn off. All of the LED current passes through D3, D4 and R5. The maximum LED current can be limited to the V_{in} voltage limit, minus the voltage of D3 and D4, divided by the value of R5.

Figure 1. LED balancing circuit 1- two string resistor divider



1.2 LED balancing circuit 2

LED balancing circuit 2 (see [Figure 2](#)) contains two bipolar transistors, eight resistors and four diodes. The current passing through each load is primarily the current through one transistor.

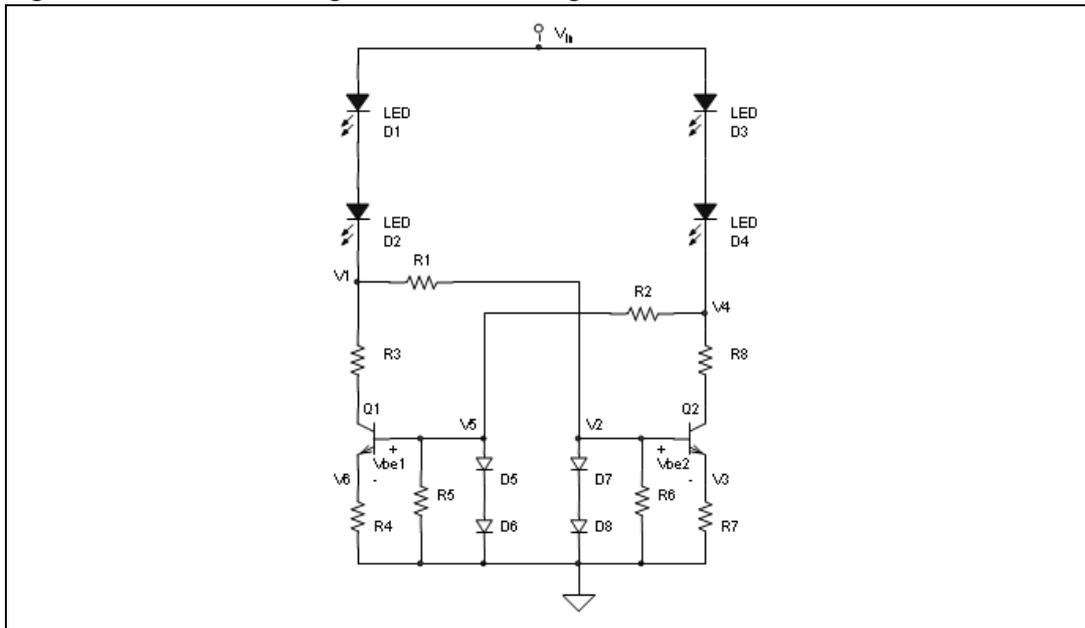
LED balancing circuit 2 uses LED loads D1 and D2, D3 and D4, and a power supply output voltage with a constant output current that provides the circuit input voltage (V_{IN}). As each string contains the same number of LEDs, any number of LEDs can be used.

The voltage at V1 is the input voltage, V_{IN} , minus the load voltage $VD1$ plus $VD2$. The voltage at V2 is the voltage drop across diodes D7 and D8. The voltage at V3 is the voltage at V2 minus V_{be2} . The current through R7 is the voltage V3 divided by the resistor R7. Conversely, the current through R4 is the voltage at V6 divided by R4. The total LED current is approximately the sum of the current through R7 and R4.

The current through each string remains approximately equal, even if the LED voltage varies or if one is shorted. This is due to the relative constant voltage of the two diodes in series (D7 and D8) which determines the current through the emitter resistor (R7).

If LED (for example D1) in one string is open, the base current for Q2 is zero, Q2 is switched off, the current through R7, which normally flows through D3 and D4, is zero and the current through D1 and D2 is zero. A small amount of current, $(V_{in} - VD3 - VD4 - VD5 - VD6)/R2$, flows through D3 and D4.

Figure 2. LED balancing circuit - two string, reference



1.3 LED balancing circuit 3

LED balancing circuit 3 (see [Figure 3](#)) balances the current in two or more parallel strings of series loads where the individual loads vary in voltage, because one is open or one is shorted. This circuit contains one bipolar transistor and resistor per string, a voltage reference and a resistor as reference. The current passing through each load is the current through one transistor.

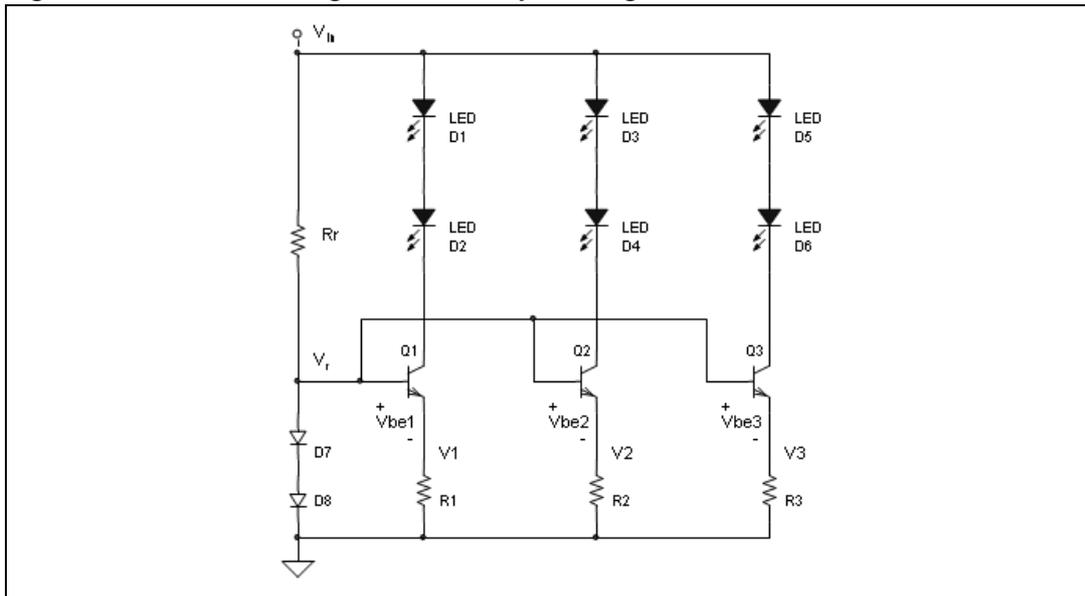
LED balancing circuit 3 uses LED loads D1 and D2, D3 and D4, D5 and D6, and a power supply output voltage with a constant output current that provides the circuit input voltage (V_{IN}). With each string containing the same number of LEDs, any number of LEDs can be used.

The voltage at V1 is the reference voltage, V_r , minus the base to emitter voltage V_{be1} . The current through R1 is the voltage V1 divided by resistor R1. Total LED current is approximately the sum of the current through the emitter resistors R1, R2 and R3.

As with LED balancing circuit 2, the current through each string remains approximately equal, even if the LED voltage varies or if one is shorted. This is due to the relative constant voltage of the reference diodes (D7 and D8 in series) which determine the current through the emitter resistors.

If a LED (for example D1) in one string is open, the current through the string (D1 and D2) is zero. The base to emitter junction of Q1 behaves like a diode and a small amount of current passes through R1. The reference voltage V_r drops, the other base to emitter junction voltages drop, and less current flow through the other strings (see [Equation 10](#)).

Figure 3. LED balancing circuit - multiple strings



2 Equations (see *Figure 3*)

2.1 Operation of LED balancing circuits where R_e represents an emitter resistor

Equation 1

$$I_{Re} = \frac{V_r - V_{be}}{R_e}$$

Equation 2

$$R_e = \frac{(V_r - V_{be})}{I_{Re}}$$

2.2 Operation of LED balancing circuits for one open LED

Equation 3

$$I_{Rr} = \frac{(V_{in} - V_r)}{R_r}$$

Equation 4

$$I_{Re} = \frac{(V_r - V_{be_{min}})}{R_e}$$

Equation 5

$$V_r = V_{be_{max}} + I_{Rr} \cdot R_e$$

Equation 6

$$V_r = V_{be_{max}} + (V_{in} - V_r) \cdot \frac{R_e}{R_r}$$

Equation 7

$$V_r = V_{be_{max}} + V_{in} \cdot \frac{R_e}{R_r} - V_r \cdot \frac{R_e}{R_r}$$

Equation 8

$$V_r + V_r \cdot \frac{R_e}{R_r} = V_{be_{max}} + V_{in} \cdot \frac{R_e}{R_r}$$

Equation 9

$$V_r = \left(\frac{V_{be_{max}} + V_{in} \cdot \frac{R_e}{R_r}}{1 + \frac{R_e}{R_r}} \right)$$

Equation 10

$$I_{Re} = \frac{\left(\frac{V_{be_{max}} + V_{in} \cdot \frac{R_e}{R_r}}{1 + \frac{R_e}{R_r}} \right) - V_{be_{min}}}{R_e}$$

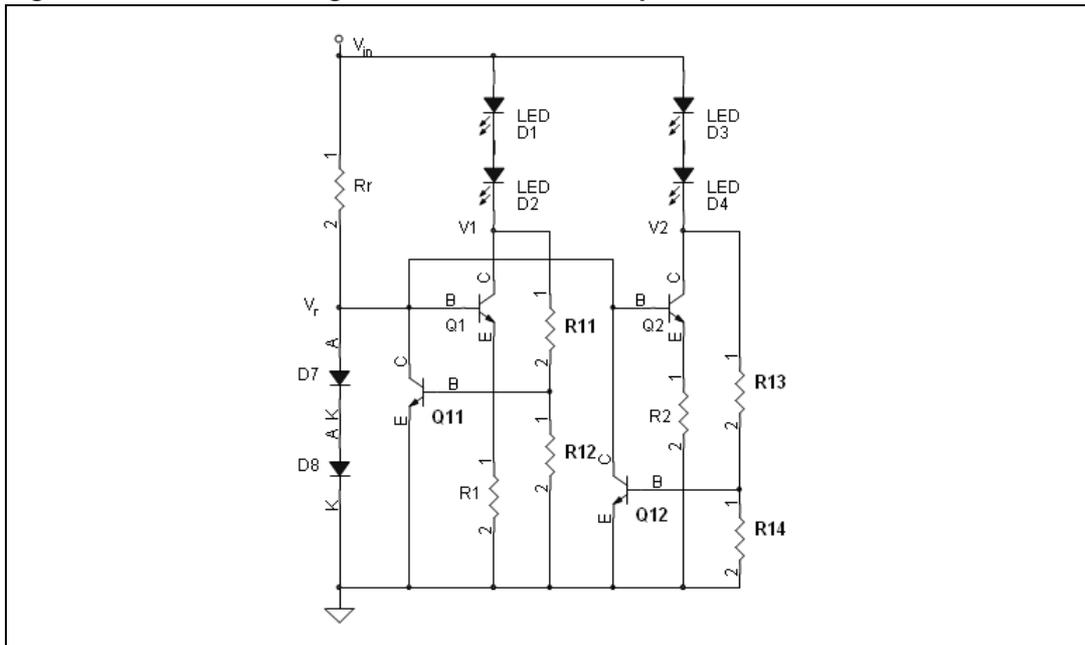
3 Power limit circuit

A power limit circuit can be added to LED balancing circuit 3 to limit the overall power when there is a large voltage variation for parallel strings of LEDs. [Figure 4](#), [Figure 5](#) and [Figure 6](#) show a power limit circuit (in bold) which has two LED strings. Voltage variation may be due to a number of factors:

- low voltage drop in a LED string
- high voltage drop in a LED string
- shortened LED string

[Figure 4](#) shows the power limit circuit comprised of R11, R12 etc. If there is a low drop in the LED string D1 and D2 ([Figure 4](#)), the voltage at V1 (Q1 collector) is high and Q11 is turned on through R11 and R12. The voltage at V_r will drop and the current in both LED strings drops. The power supply source, which has a constant current source, tries to supply the required current, and will raise the output voltage up to the power supply output voltage limit. V_{in} and V1 increase, and Q11 latches on and disables the LED balancing circuit until V_{in} is removed.

Figure 4. LED balancing circuit - two transistor power limit, latch



The following two circuits are variations of the power limit circuit in [Figure 4](#). They disable the LED balancing circuit but will not latch it off.

[Figure 5](#) shows a one transistor power limit LED balancing circuit (R11, R12 etc.). It has fewer parts but a narrower fault tolerance detection range. Q11 is turned on through either R11 or R13.

[Figure 6](#) shows a two diode power limit LED balancing circuit (R11, R12 etc.). Q11 is turned on through diodes D9 or D10

Figure 5. LED balancing circuit - one transistor power limit

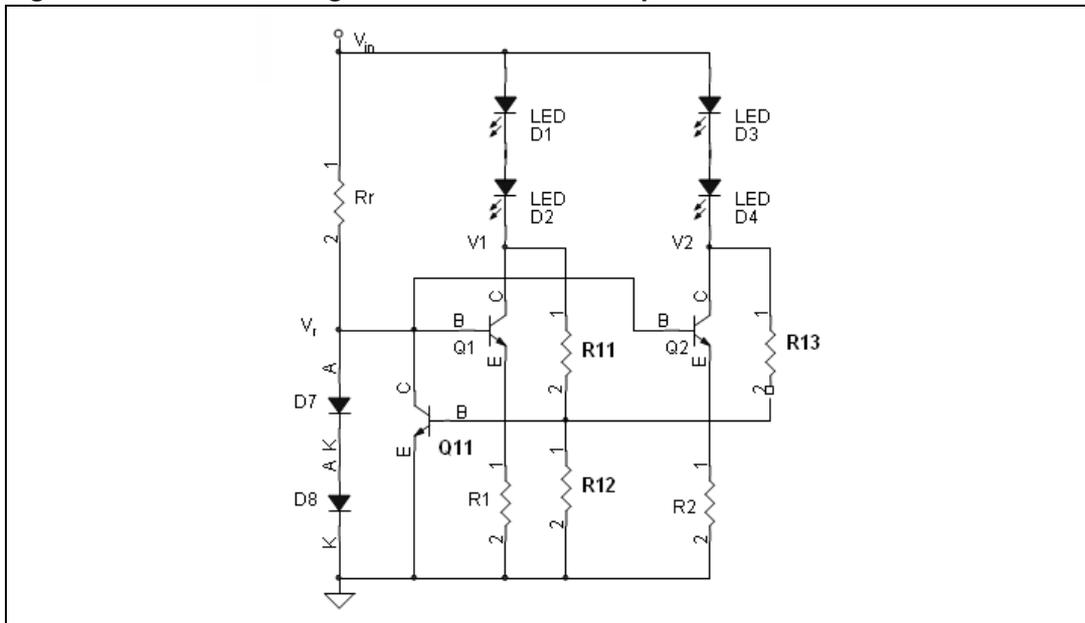
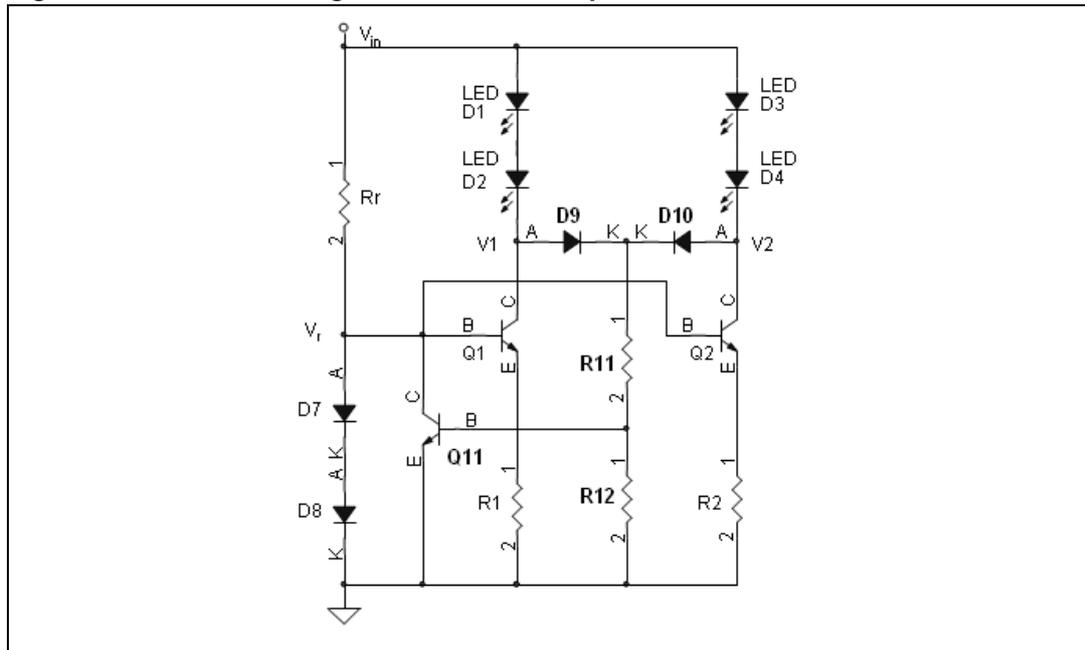


Figure 6. LED balancing circuit - two diode power limit



4 Revision history

Table 1. Revision history

Date	Revision	Changes
31-Jan-2007	1	First issue
05-Apr-2007	2	Cross references updated

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